AD-746 760

MISCELLANEOUS PAPER M-69-2

VEHICLE DYNAMICS RESEARCH AT WATERWAYS EXPERIMENT STATION

by

A. J. Green, Jr.
G. G. Switzer

June 1969

Sponsored by

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

Destroy this report when no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

MISCELLANEOUS PAPER M-69-2

VEHICLE DYNAMICS RESEARCH AT WATERWAYS EXPERIMENT STATION

by

A. J. Green, Jr.

G. G. Switzer

June 1969

Details of illustrations in this document may be better studied on microfiche

Sponsored by

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS

FOREWORD

The research described herein is conducted by personnel of the Vehicle Dynamics Section (VDS), Mobility Research Branch (MRB), Mobility and Environmental (M&E) Division, U. S. Army Engineer Waterways Experiment Station (WES). This research is guided and sponsored by the Directorate of Development and Engineering, U. S. Army Materiel Command, under DA Project No. 1T062103A046, "Trafficability and Mobility Research," Task 03, "Mobility Fundamentals and Model Studies," and DA Project No. 1T061102B52A, "Research in Military Aspects of Terrestrial Sciences," Task 01, "Terrain Aspects of Off-Road Mobility."

The studies are pursued under the general supervision of Messrs. W. G. Shockley and S. J. Knight, Chief and Assistant Chief, respectively, of the M&E Division, and under the direct supervision of Dr. D. R. Freitag, Chief of the MRB, and Mr. A. J. Green, Chief of the VDS.

This paper was prepared for presentation at the Off-Road Mobility Research Symposium, sponsored jointly by Cornell Aeronautical Laboratory, Inc., and the International Society for Terrain Vehicle Systems, and held in Washington, D. C., on 26-27 June 1968. The paper was subsequently published in the proceedings of that symposium.

At the time this paper was prepared and presented, COL Levi A. Brown, CE, was Director of WES, and Mr. J. B. Tiffany was Technical Director.

VEHICLE DYNAMICS RESEARCH AT WES

by

A. J. Green and G. G. Switzer

U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi, U.S.A.

One mission of the Mobility and Environmental Division of the U. S. Army Engineer Waterways Experiment Station (WES) is to conduct research that will lead to an improvement in the mobility of ground-contact military vehicles. This research began at WES more than 20 years ago (just prior to the end of World War II) and has resulted in substantial contributions to the state-of-the-art. Among the achievements are:

a. The development of systems for the prediction of the performance of vehicles in soft soils.

b. The development of schemes for evaluation and classification of terrain in terms that are compatible with military requirements.

c. The development of an analytical model of the vehicle and its environment that will yield an estimate of cross-country mobility, including speed and delivery rates, regardless of the terrain complex encountered.

The last item above encompasses the many facets of the mobility problem, such as performance of vehicles on soft soils and at the land-water interface, tree override, vehicle ride, and others. In some facets, the

TEST FACILITIES AND EQUIPMENT

Facilities and Test Courses

Facilities for mobility research at the WES include one with movable soil bins for small-scale testing (fig. 1), and another with three permanent test pits for large-scale testing (fig. 2). The movable bins are 8.23 m long, 1.63 m deep, and 0.81 m wide; two of the permanent pits are 51.8 m, 1.52 m, and 3.55 m, and the third is 51.8 m, 1.52 m, and 6.10 m.

In addition to the indoor facilities, there is a recently constructed outdoor facility (fig. 3). It was designed so that surface roughness can be controlled. Various shapes and sizes of obstacles can be bolted or welded to slotted metal channels imbedded in concrete footings. The obstacle area is 61 m long and 15 m wide, with an acceleration lane 183 m long cleared at one end. This design permits the experimenter to adjust the spatial frequency of the obstacles and vehicle velocity in a fashion that will excite one or more of the natural frequencies of the vehicle. It is felt that in many instances this type of testing affords as important a comparison of the capabilities of two or more vehicles as the practice of comparing two or more vehicles on a specific terrain.

A permanent test track that is an analog of several specific terrains is also useful, however, in model verification and comparative analysis of vehicle ride. Hopefully, such a test track will be built at WES and should contain a variety of types of surface roughness--different amplitudes, spacings, etc.

Test Vehicles

The M37, 3/4-ton tr... selected to begin the vehicle dynamics research because WES and other ... had already accumulated a significant store of data on it. An M37 ... instrumented with orthogonal sets of accelerometers mounted at the ... driver's seat, the center of gravity of the vehicle, and the center of ... cargo area, so that dynamic response can be measured at each of these ... Pitch and roll can be measured at the vehicle's center of gravity. ...ty and distance traveled are obtained by using a wire pay-out device, ... with a tachometer, that produces an electrical pulse every 15 cm of ...cle travel. The torque output is measured at the rear of the transmission.

The 4x4 test vehicle ... fig. 4, though originally designed for use in conjunction with soft-... performance tests in the laboratory, was found to be suitable for the ... dynamics research program as well. It has sufficient power to accept a wide variety of tires including many of those designed for off-road use. ... assets are air springs, easy access to shock absorber hookup points, and ... of loading and unloading.

While the vehicles ... have been used with success thus far in the WES program, a specially designed test bed would be more useful. The framework of this test bed should be such that the following features could be selected as required:

a. Number of ... axles

b. Wheelbase and ... spacings

c. Shock absorb... ...ing rates

d. Suspension ... rates

e. Tire sizes

f. Frame stiffness

g. Vehicle loads and wheel loads.

Such a system would permit systematic evaluation of new or improved modeling techniques, and optimization of the characteristics of the suspension system or other vehicle components.

Drop Test Apparatus

A drop test apparatus, as the name implies, is used to suspend and drop vehicles. When the vehicles are properly instrumented, this type of test provides valuable information regarding the natural frequencies of several components and the damping or decay rates at several locations on the vehicle. Fig. 5 shows an M37 in place in preparation for a drop test.

Computer Facilities

Vehicle dynamics analysis requires high-speed computing. Digital computing facilities currently being used for this purpose include a CDC-3800 located at the Environmental Sciences Services Administration Computing Center, Boulder, Colorado; an in-house general-purpose machine (GE-225); and a time-shared link to a remote machine (GE-420). At the present, WES has a modest in-house analog simulation capability (Systron Donner SD/80, a machine with 84 operational amplifiers plus digital control circuits). This latter facility has been used extensively in modeling vehicle components and processing vehicle test data. Prior to its acquisition, analog and hybrid computer facilities at the Simulation Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama, were used.

The nature of the vehicle-terrain simulation problem makes hybrid systems the best choice for computing. In view of this, tentative plans have been made for developing an in-house capability for handling a variety of vehicle simulation problems. These plans include increasing present analog capabilities twofold to threefold and acquiring a compatible digital processor. The in-house digital equipment (GE-225) will be replaced by a GE-420 during the calendar year 1968.

Dynamometers

Three dynamometer systems have been developed for mobility laboratory testing at WES. That shown in fig. 6 is being used to study the dynamic properties of pneumatic tires. Instrumentation on the system provides for continuous records of torque, wheel speed, carriage speed, pull, wheel load, tire deformation, vertical hub displacement, and vertical and horizontal acceleration. This system can accommodate wheels up to 88.9 cm in diameter, can be propelled at speeds up to 9.14 m per second, and can be loaded to 8888 N. The larger system, shown in fig. 7, is being used to study the dynamic properties of large tires (up to 2.13 m in diameter), including sizes that are used on a variety of off-road commercial and military vehicles, and it can be instrumented for the same records as above.

A track dynamometer system is shown in fig. 8. It can be instrumented to record continuously torque, track and carriage speed, pull, tilt, track tension, load and load distribution, vertical displacement of the system and/or individual road wheels, and vertical and horizontal acceleration.

REVIEW OF ACTIVITIES

Current activities at WES include the development of improved techniques for representing the compliance of traction and transport elements (e.g. tire and track), an investigation of the dynamic properties of tires, and field tests with an instrumented vehicle.

Among the crudest of the approximations commonly being utilized in vehicle modeling is the representation of the compliance of tires and tracks. The wheel of a pneumatic-tired vehicle has been most often represented by a single spring and dashpot, but research by WES and others has indicated that this simulation is unrealistic because the tire has a finite footprint length and the ability to envelop or partially envelop small obstacles in its path. Thus, it is felt that tire compliance can be simulated more accurately by employing a segmented wheel concept.

The concept of a segmented wheel has been the subject of a recent study at WES, in which it has been learned that a segmented version of the wheel can be developed for a given tire when the overall load-deflection inflation-pressure relation for that tire is known. The vertical response of a point contact model and response of a segmented system are compared to actual test data in fig. 9. Both horizontal and vertical responses of the segmented wheel model are compared to test data in fig. 10. The prediction of horizontal responses is a natural product of the segmented system, while a horizontal input to the axle from a point contact model can be obtained only by special computing techniques for estimating the angular position of the resultant force acting on the wheel.

Track systems are most often represented by a series of nondeforming

road wheels. Thus the contact of the track with the ground in the spaces between the road wheels is ignored. Obviously, this omission can affect the reliability of any model of a tracked vehicle. WES personnel are attempting to develop a segmented track concept that will recognize the contribution provided to the overall dynamic response of the vehicle by the portion of the track between the road wheels. The accuracy of the segmented track model will be evaluated by determining the effect of track tension, road wheel spacing, load, and load distribution on the obstacle performance or vibrational activity of the track dynamometer system shown in fig. 7.

Recently, work was initiated on the development of models for deforming soils that will be compatible with the tire and track models. This work has not yet reached a stage where results can be shown.

As stated previously, the dynamometer system shown in fig. 6 is being used, together with other equipment, to study the dynamic properties of pneumatic tires. Spring and damping rates for stationary and rolling pneumatic tires and the reaction of tires as they envelop small obstacles and traverse vertical steps are being determined. A portion of these data was used to assess the validity of the segmented wheel concept.

During the past six months, field studies have been conducted with an instrumented M37, 3/4-ton truck to validate existing criteria and/or develop new criteria for estimating the cross-country speed of vehicles. The test program to date has been limited to traversal of single and multiple obstacles at selected vehicle speeds, and most of the tests have been simulated on the computer. Future testing will include tests on rough terrain at selected speeds, and tests in which the driver is free to select a "tolerable" speed.

The literature contains a variety of schemes for establishing comfort

or endurance limits for humans traveling in vehicles over rough terrain. Most schemes, however, do not specifically include a time factor.. While it is generally understood that these criteria apply to vibrations lasting for several minutes, additional criteria are required for estimating the response of the driver and vehicle to relatively high acceleration forces of short duration (less than 1 min). An interesting and promising outcome of recent experimentation with vehicle dynamics data reduction has been the development of an indicator of vehicle vibration for single-obstacle traversal. It is calculated as a short-term root-mean-square acceleration:

$$I = \left(\frac{1}{T} \int_0^T a^2 dt \right)^{1/2}$$

where T is the time required for the vehicle to traverse 4.57 m (1-1/2 vehicle lengths) after initial impact with the obstacle, and a is the resultant of horizontal, vertical, and lateral acceleration (in g's) at a point of interest on the vehicle. For the case of acceleration at the driver's seat, fig. 11 shows how the indicator I varies with vehicle speed. As can be seen, agreement between measured and predicted values is quite good. Attempts are being made to relate this term to vehicle damage and the driver's subjective evaluation of ride severity.

SUMMARY

Existing research facilities at WES are being utilized in a systematic approach to developing and validating more reliable models of the man-vehicle-terrain system. Specific attention is being given to developing more realistic models of tires, tracks, and deforming soil. The dynamometer systems at WES are being utilized to evaluate these models and to determine

dynamic characteristics of certain tires and track systems.

High-speed computing facilities are being used extensively, and capabilities for in-house simulation activities are being increased.

Obstacle courses and test tracks will be used to evaluate analytical models and assess the validity of criteria for determining ride quality and/or vehicle speed.

BIBLIOGRAPHY

1. Dieckmann, D., "Einfluss Vertihaler Mechanischer Schwingungen auf den Menschen," Internat. Z. Angew Physol., Vol 16, 1947, pp 519-564.
2. Ettling and Trimble, "Ride Comfort Evaluation by Cross-Modality Matching," Report TR-T-792, Dec 1961, Ford Motor Company.
3. Goldman, D. E., "A Review of Subjective Responses to Vibratory Motion of the Human Body in the Frequency Range 1 to 70 cps," Report 1, Proj. N.M.-004C01, Mar 1948, Naval Medical Research Institute, National Naval Medical Center, Bethesda, Md.
4. Harris and Crede, Editors, Shock and Vibration Handbook, McGraw-Hill, Inc., New York, 1961.
5. Janeway, R. N., "Vehicle Vibration Limits to Fit the Passenger," Preliminary copy of paper to be presented at SAE Passenger Car and Production Meeting, Detroit, Mich., 5 Mar 1948.
6. Kozin, F., Cote, L. J., and Bogdanoff, J. L., "Statistical Studies of Stable Ground Roughness," Report No. 8391, Nov 1963, U. S. Army Tank-Automotive Center, Warren, Mich.
7. Lee, R. A., and Pradko, F., "Analytical Analysis of Human Vibration,"

Paper No. 680091, SAE Automotive Engineering Congress, Detroit, Mich., 8-12 Jan 1968.

8. Magid, E. B., Coermann, R. R., and Ziegenruecker, G. H., "Human Tolerance to Whole Body Sinusoidal Vibration," Journal of Aerospace Medicine, Vol 31, Nov 1960, pp 915-924.

9. Pradko, F., Lee, R. A., and Kaluza, V., "Human Tolerance of Random and Sinusoidal Acceleration," Systems Simulation Branch, Advanced Systems and Concept Research Division, U. S. Army Tank-Automotive Center, Warren, Mich., Apr 1965.

10. __________, "Theory of Human Vibration Response," Paper 66-WA/BHF-15, ASME Winter Annual Meeting and Energy Systems Exposition, New York, 27 Nov-1 Dec 1966.

11. Stevens, S. S., "Cross-Modality Validation of Subjective Scales for Loudness, Vibration, and Electric Shock," Journal of Experimental Psychology, Vol 57, 1959a, pp 201-209.

12. Van Deusen, B. D., "Data Acquisition and Statistical Analysis Using Analog Computer Techniques," SAE Transactions, 1963, pp 350-357.

13. __________, "A Study of the Vehicle Ride Dynamics Aspect of Ground Mobility; Volume II, Human Response to Vehicle Vibration," Contract Report No. 3-114, Mar 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. (Chrysler Corporation, contractor).

14. __________, "Human Response to Vehicle Vibration," Paper No. 680090, SAE Automotive Engineering Congress, Detroit, Mich., 8-12 Jan 1968.

15. Ziegenruecker, G. H., and Magid, E. B., "Short Time Human Tolerance to Sinusoidal Vibrations," WADC TR 59-391, July 1959.

CONVERSION FACTORS, METRIC TO BRITISH UNITS OF MEASUREMENT

Metric units of measurement used in this paper can be converted to British units as follows:

Multiply	By	To Obtain
meters	3.2808	feet
centimeters	0.3937	inches
newtons	0.2250	pounds force
kilonewtons per square meter	0.145	pounds force per square inch

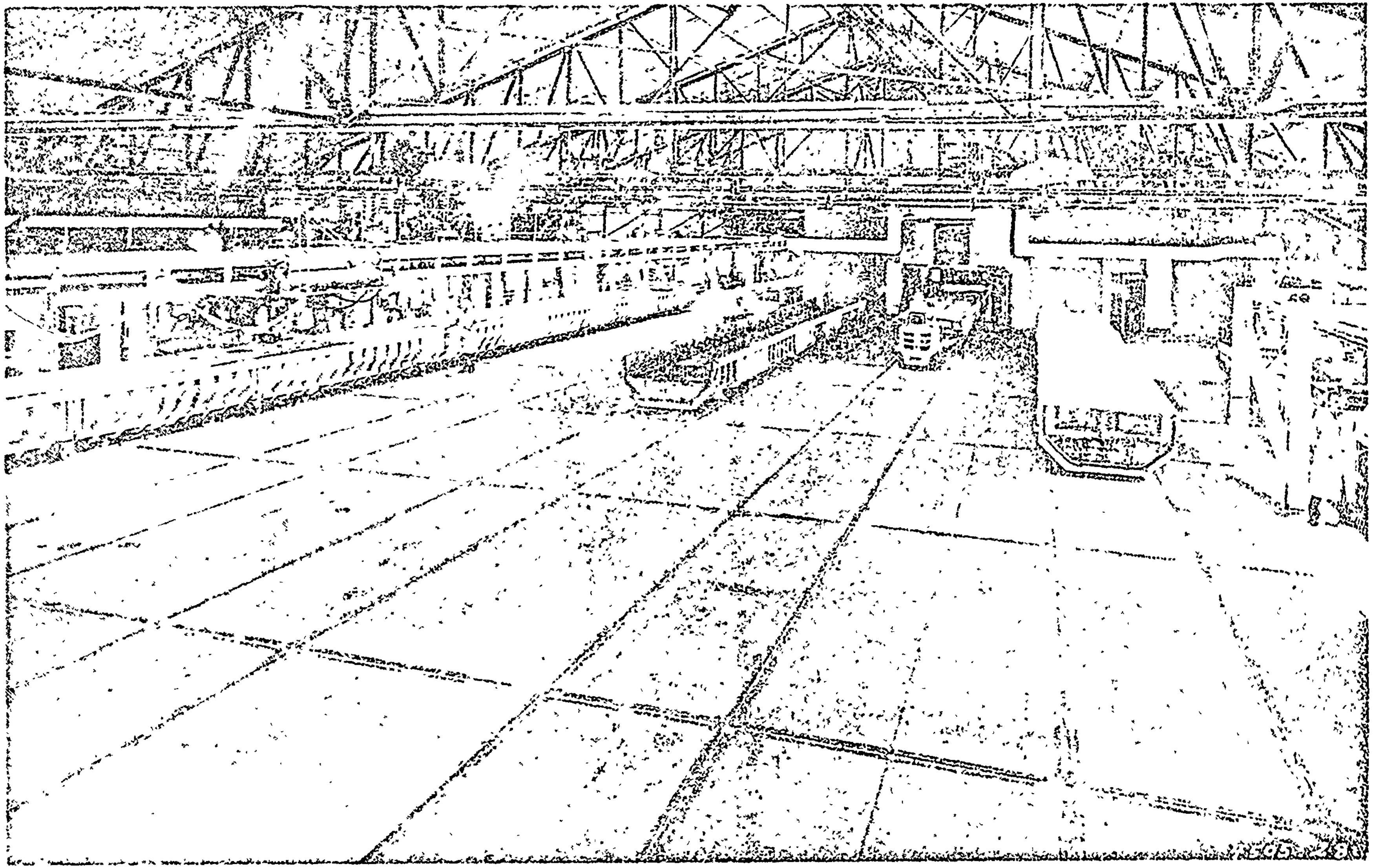


Fig. 1. Small-scale testing facility

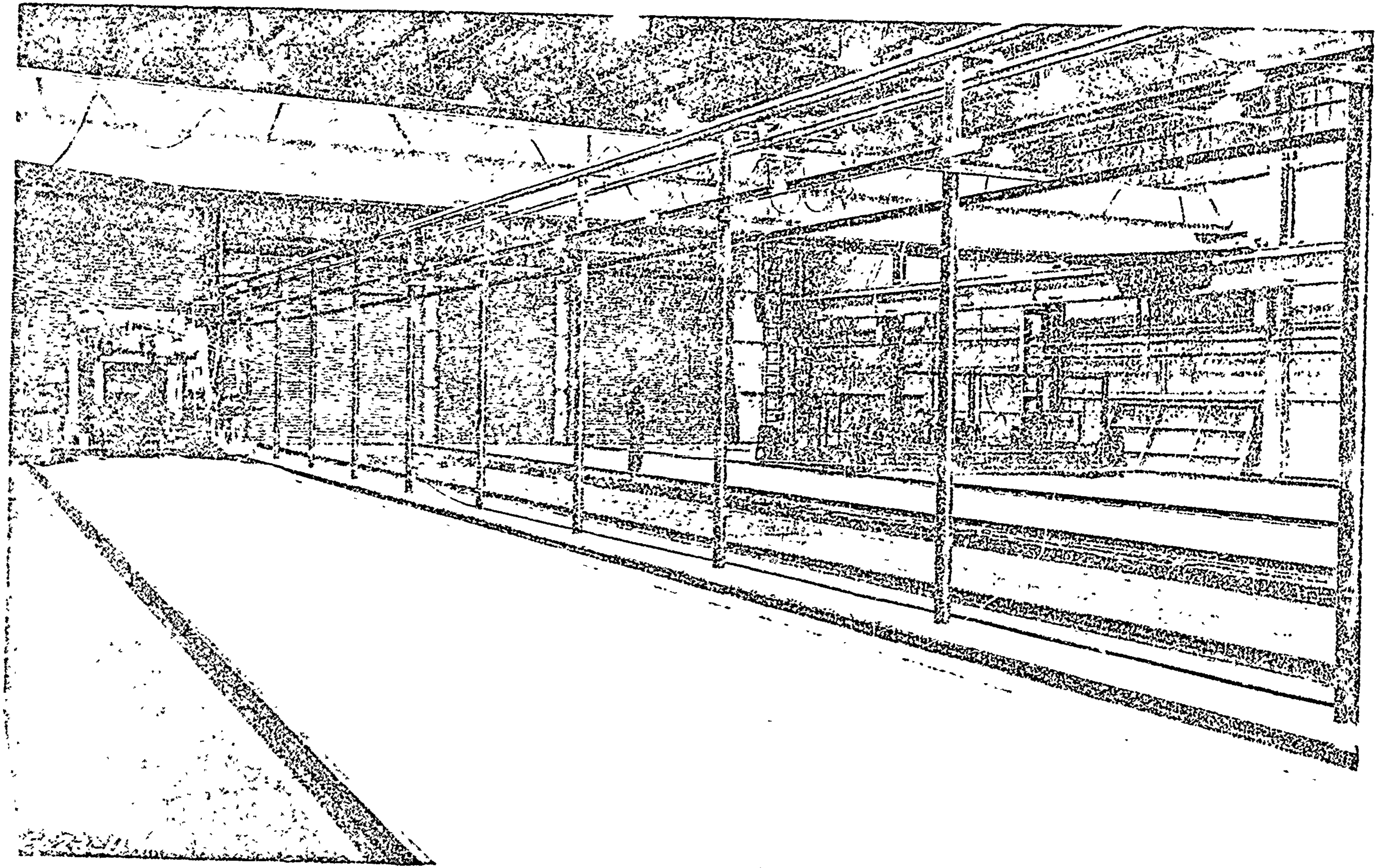


Fig. 2. Large-scale testing facility

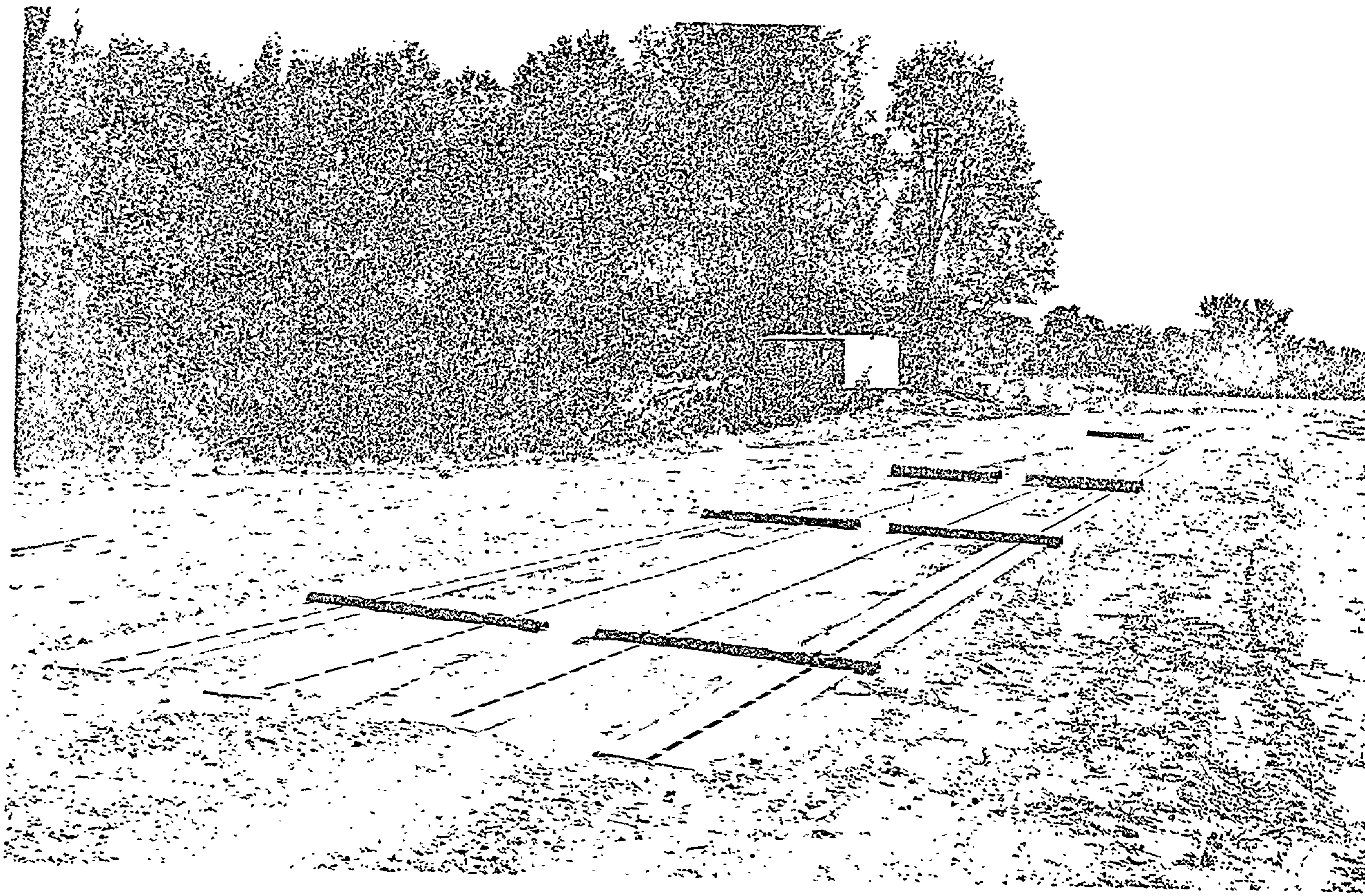


Fig. 3. Obstacle test course

Fig. 4. 4x4 test vehicle equipped with Terra-tires

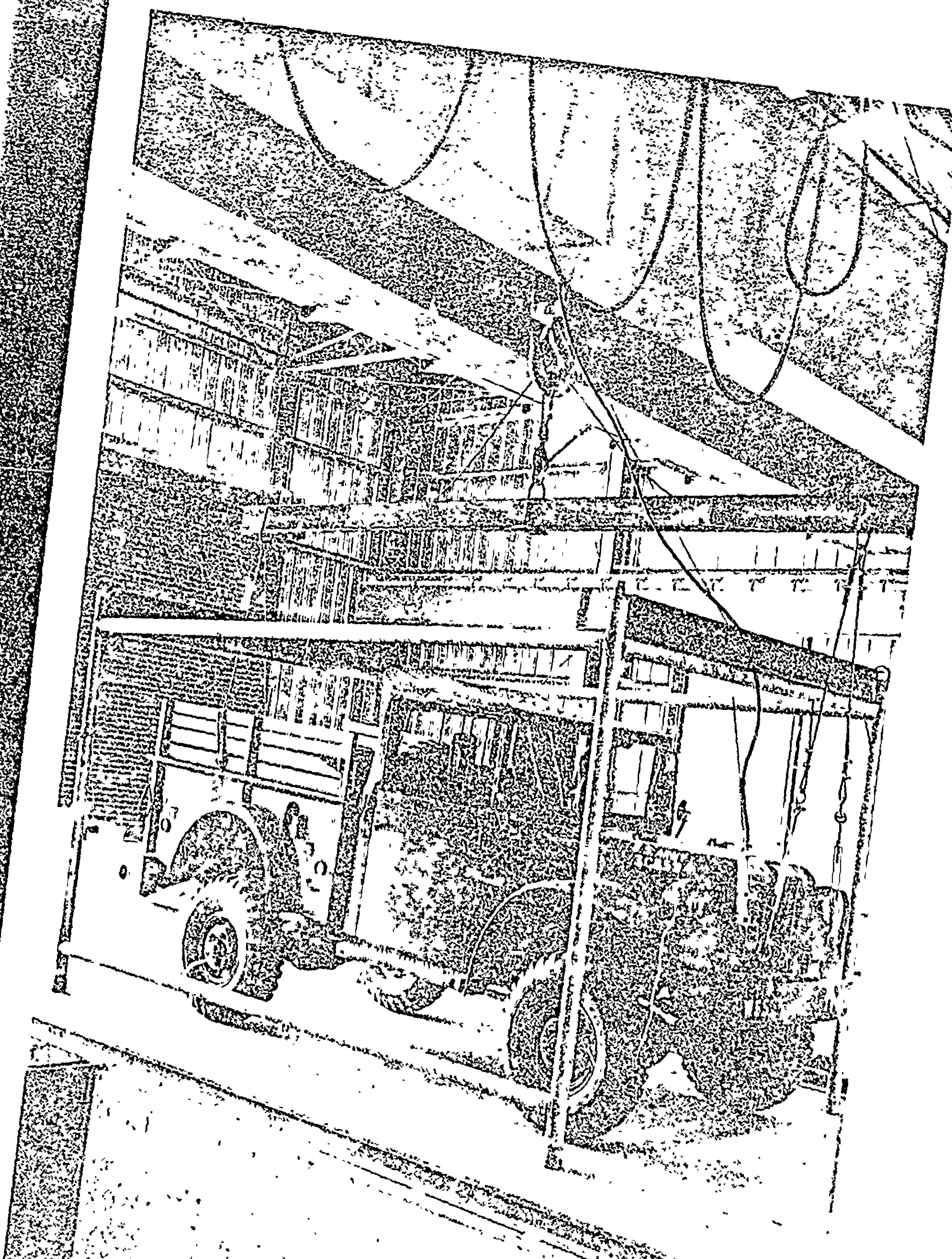


Fig. 5. M37, 3/4-ton truck in position for drop test

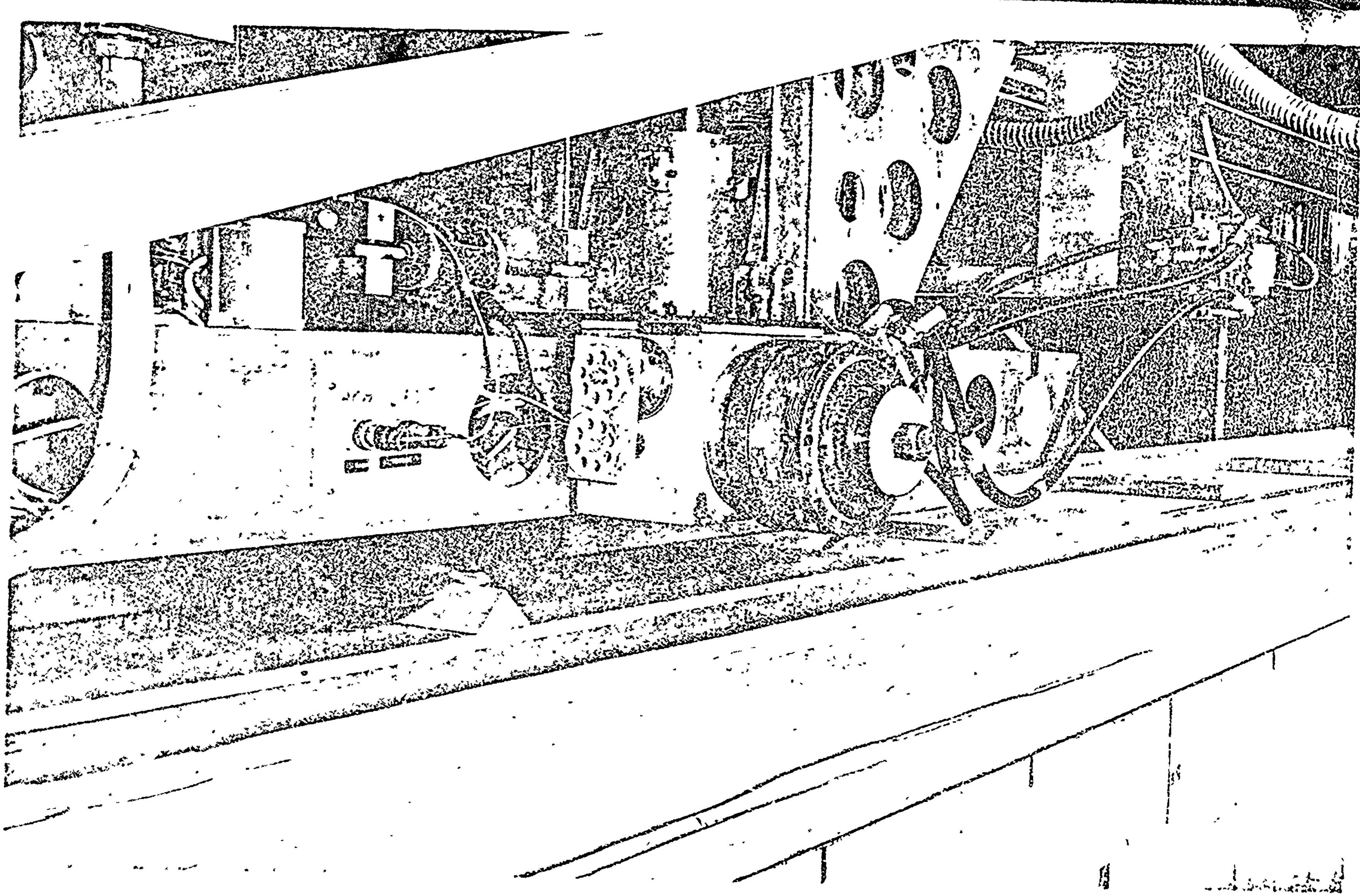


Fig. 6. Dynamometer system in small-scale testing facility

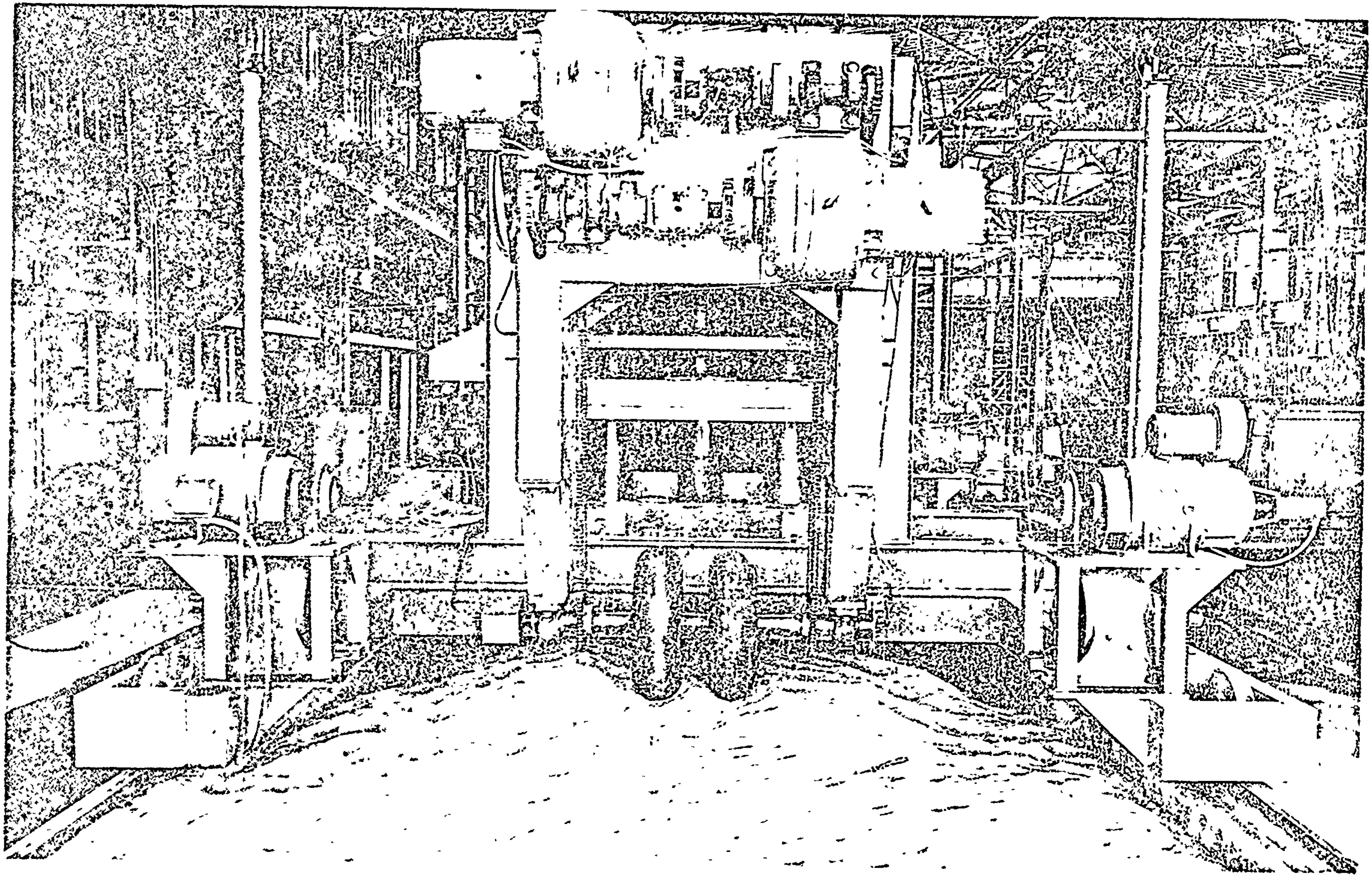


Fig. 7. Dynamometer system in large-scale testing facility

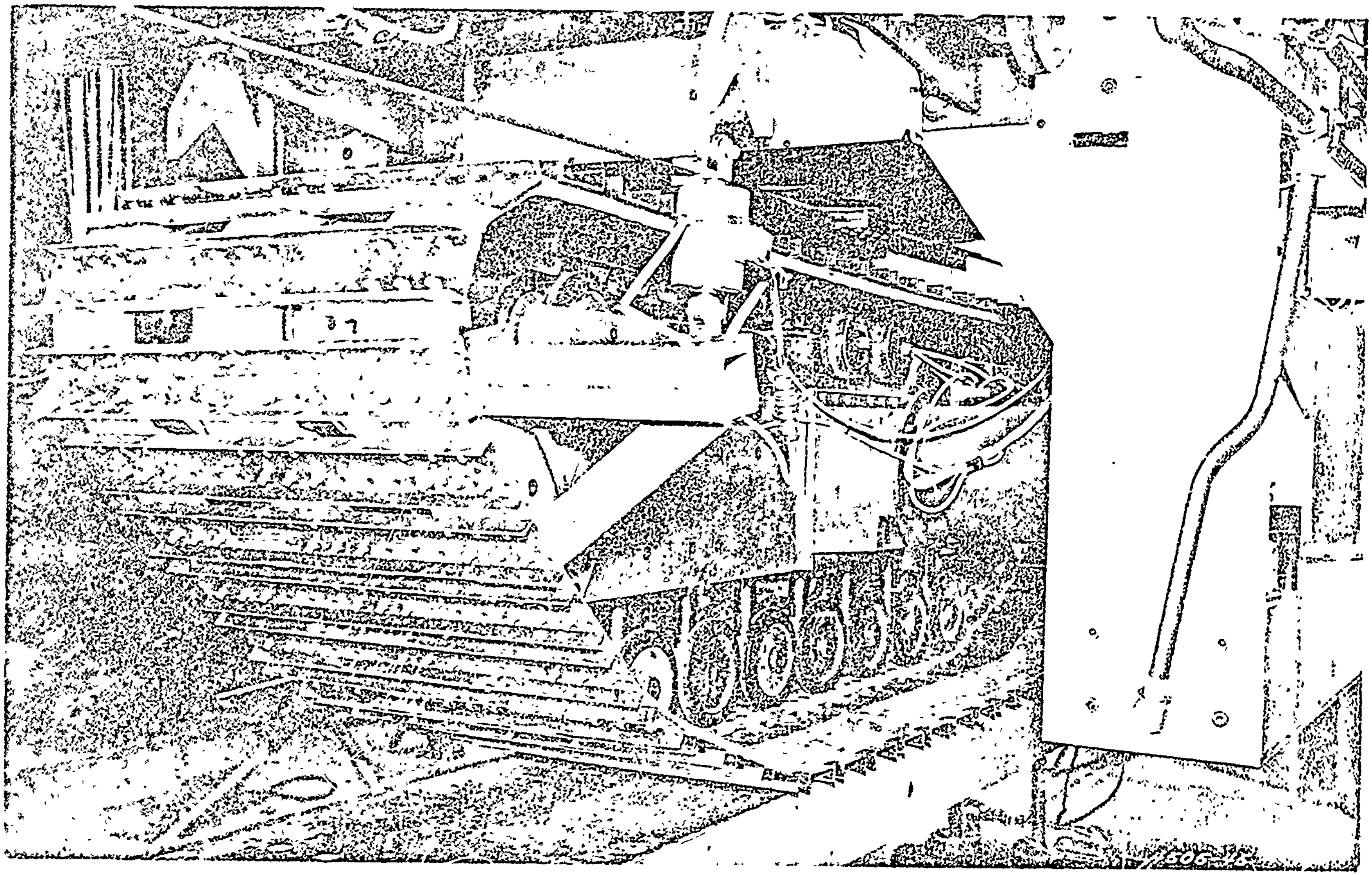
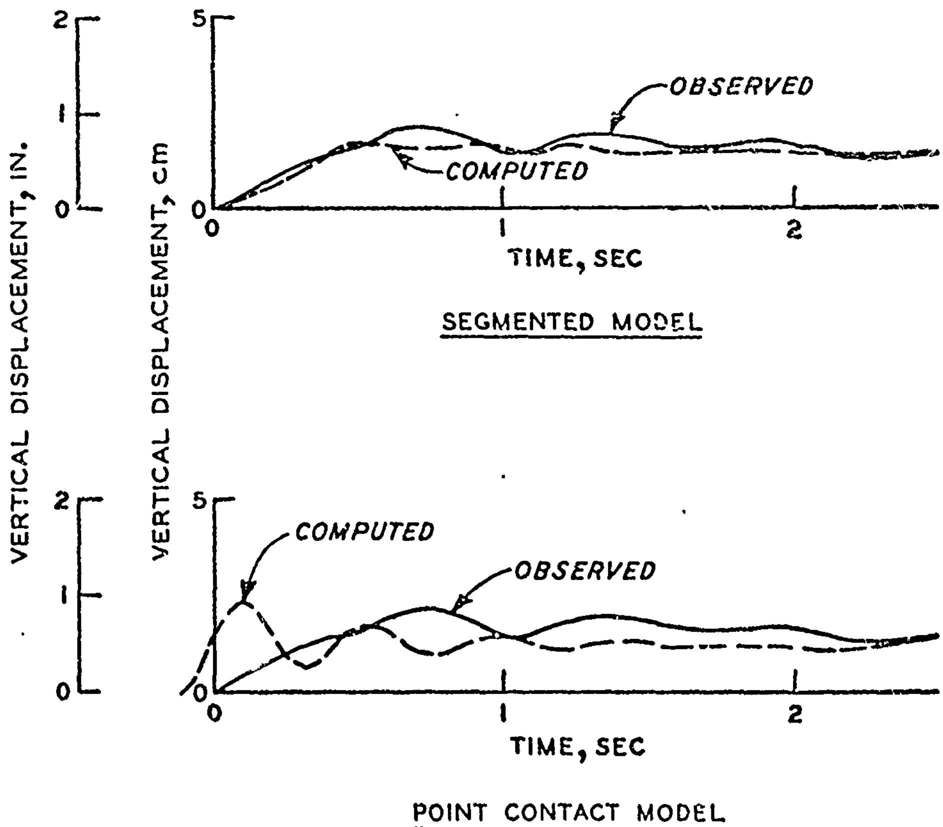


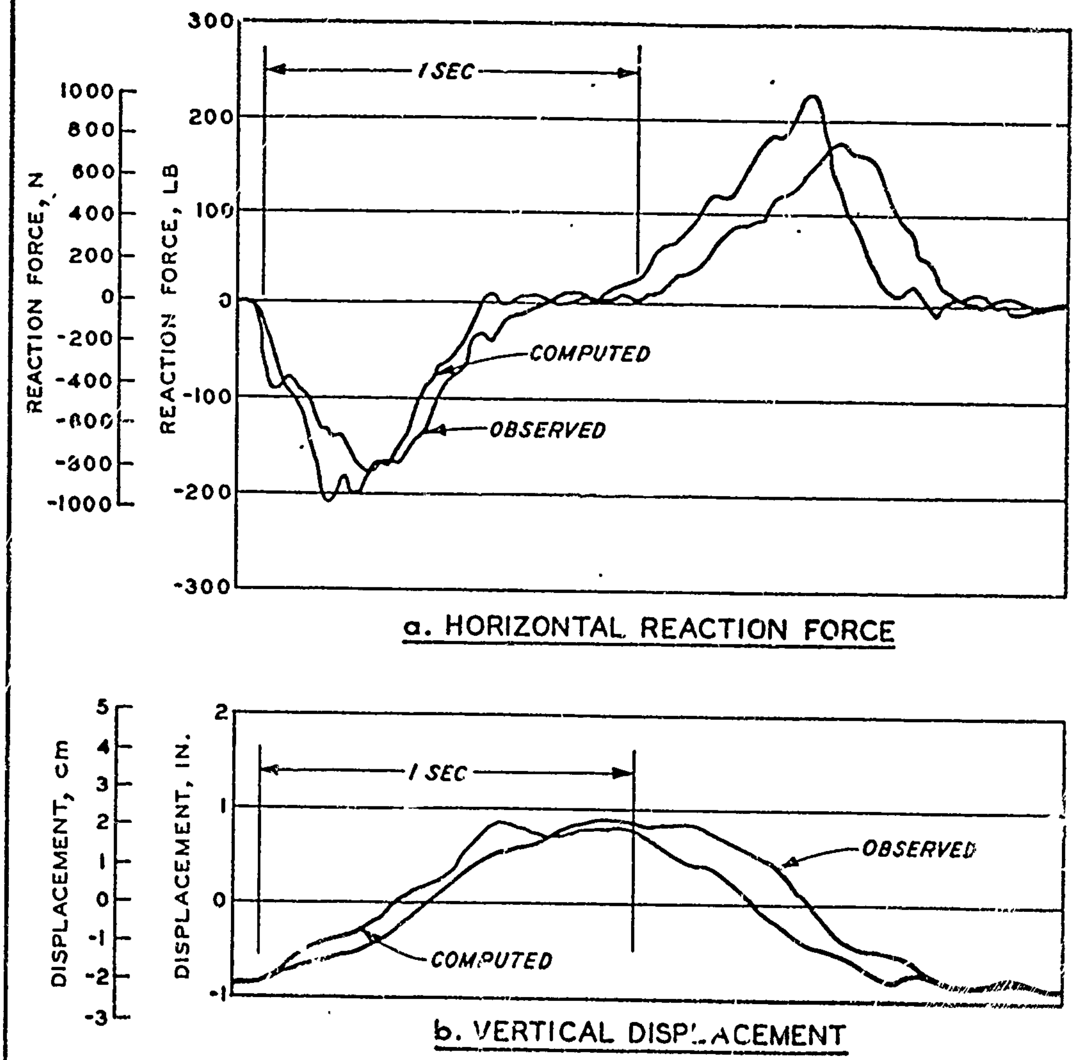
Fig. 8. Track dynamometer system in small-scale testing facility



COMPARISON OF EMPIRICAL AND ANALYTICAL RESULTS

2222-N LOAD
138 kN/m^2 INFLATION PRESSURE
CARRIAGE SPEED, 0.8 m/SEC
9.00-14, 2-PR TIRE

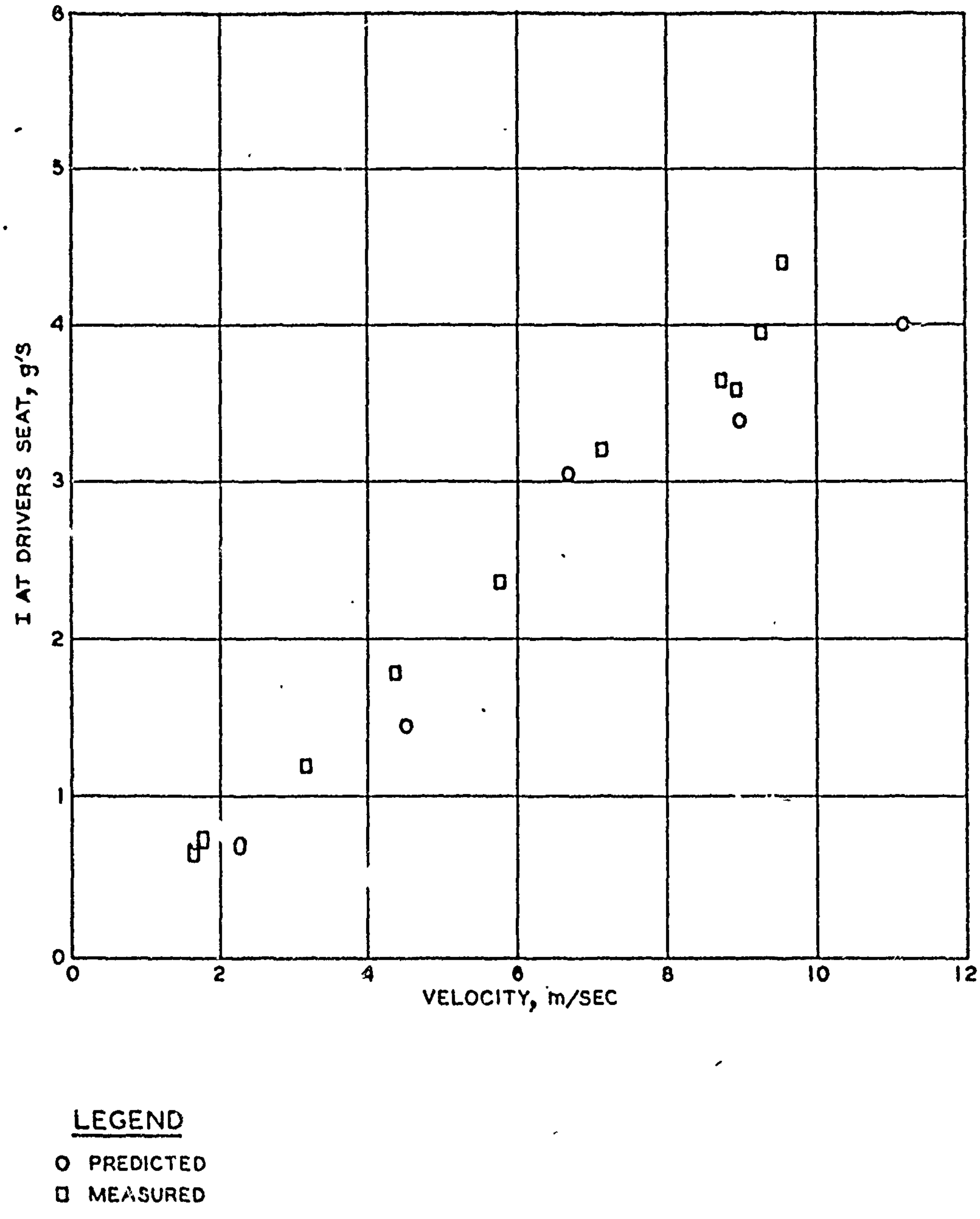
Fig. 9



COMPARISON OF
EMPIRICAL AND
ANALYTICAL RESULTS

2222-N LOAD
207 kN/m² INFLATION PRESSURE
CARRIAGE SPEED, 0.3 m/SEC
9.00-14, 2-PR TIRE

Fig. 10



EFFECT OF SPEED
ON VEHICLE RESPONSE
M37 TRUCK
20-cm HALF-ROUND
OBSTACLES

Fig. 11

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Engineer Waterways Experiment Station Vicksburg, Miss.	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

VEHICLE DYNAMICS RESEARCH AT WATERWAYS EXPERIMENT STATION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final report

5. AUTHOR(S) (First name, middle initial, last name)

Andrew J. Green, Jr.
Gerald G. Switzer

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1969	24	15

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Miscellaneous Paper M-69-2 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Materiel Command Washington, D. C.

13. ABSTRACT

Existing research facilities at U. S. Army Engineer Waterways Experiment Station (WES) are being utilized in a systematic approach to developing and validating more reliable models of the man-vehicle-terrain system. Specific attention is being given to developing more realistic models of tires, tracks, and deforming soil. The dynamometer systems at WES are being utilized to evaluate these models and to determine dynamic characteristics of certain tires and track systems. High-speed computing facilities are being used extensively, and capabilities for in-house simulation activities are being increased. Obstacle courses and test tracks will be used to evaluate analytical models and assess the validity of criteria for determining ride quality and/or vehicle speed.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Dynamometers						
Mathematical models						
Vehicle dynamics						

Unclassified
Security Classification